JOURNAL OF MATERIALS & CONSTRUCTION

Journal of Materials and Construction
ISSN 2734-9438
Website: www. jomc.vn

# The study of force-resistance of reinforced geopolymer concrete beam

**Le Huu Quoc Phong[1*], Le Hoang [1]**

[1] Can Tho University of Technology, No. 256, Nguyen Van Cu Street, An Hoa Ward, Ninh Kieu District, Can Tho City

KEYWORDS

Geopolymer
Fly ash
Mechanical properties

ABSTRACT

During the recent decades, the development of geopolymer concrete technology towards to produce an alternative construction material solution for replacing the Ordinary Portland Cement (OPC) concrete. Compared to traditional concrete, the products using geopolymer material can reduce the significant amount of carbon footprint and positively impact the environment. This study demonstrated that the flexural force-resistance of Geopolymer concrete (GPC) is higher than the OPC concrete, especially the higher flexural strength about 20% to 30%. Meanwhile, the Poisson's ratio and elasticity modulus of geopolymer concrete is equivalent to OPC concrete.

## 1. Introduction

Nowadays, concrete is used as the most widespread distribution in construction material. Besides the advantage of mechanical properties, it uses rough material sources everywhere and easily repairs or shapes. However, it also has obsolete issues warned by the abundant research as a pollution problem, increasing greenhouse effect. Significantly, the process of concrete production created a tremendous amount of Carbon dioxide; this is around 88% of total gas emission. To solve these problems, numerous researchers of green materials were developing solutions to combine or replace partial cement. Therein, the investigations of geopolymer material demonstrate that it is able to replace the traditional material for long-term settlement, specifically, replacing concrete using traditional cement.

The reaction of fly ash and alkaline solution is the foundation for producing a new type of material named Geopolymer Concrete [1-2]. The procedure to have geopolymer material shows in Figure 1, the aluminosilicate source is geopolymerization using alkaline activation. This geopolymerization is a highly complex progress and uncleared explanation at present because the process is not a step-by-step procedure, all reactions are overlapping performed at once. [3].

Geopolymer concrete technology has attracted increasing interest from researchers and material investment companies worldwide in the past two and current decades. The previous results indicated that GPC can be considered a green material and is widely applied in technology and technical construction. Therefore, they propose using GPC to replace traditional cement because of much potential in mechanical properties. Nevertheless, those researches are still not shown fully understanding and sufficient analysis data about this such concrete.

Palomo, Grutzeck, and Blanco (1999) [5] studied the impact of ratio of alkaline to fly ash (AK/FA), curing temperature, curing time to geopolymer concrete strength. The results showed that both time and temperature also affect strength. The combination of sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$) can increase the higher compressive strength to 60Mpa at the temperature of 85oC and curing time of 5 hours.

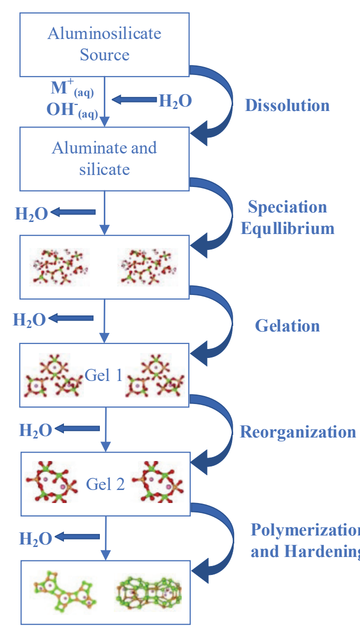



**Figure 1.** A conceptual model for geopolymerization. [4]

Van Jaarsveld, Van Deventer and Lukey (2002) [6] analyze the complicated properties of this such concrete, which is affected by the dissolution of some unique materials during geopolymerization progress. These authors also agreed about the effect of curing time and temperature on concrete strength. The research indicated that the longer the curing time is, the higher concrete strength increases.

Based on the several tests on the effective geopolymerization to the compressive strength of concrete added fly ash, Phong and Tu (2018) [7] went to the following conclusion:

Corresponding author: lhqphong90@gmail.com
Received 04/05/2022, Revised 25/07/2022, Accepted 15/08/2022
Link DOI: https://doi.org/10.54772/jomc.v12i02.380

The strength of GPC depends on the activated process between alkaline solution and fly ash, the ratio of $Na_2SiO_3$ to NaOH. In addition, the curing condition that includes time and temperature, also changes geopolymer structures.

- ✓ The strength of GPC shows an upward trend when the AS/FA ratio is higher. The fact is that when this ratio changes from 0.4 to 0.5, then the strength hits the highest points, but this trend slightly increases for this ratio of 0.6.
- ✓ It notes that the ratio of $Na_2SiO_3$ to NaOH at 2.5 is the best ratio and is proposed use for all aggregate geopolymer concrete.
- ✓ Curing time and temperature support geopolymer progress to be faster, and concrete early reaches strength. Concrete strength rapidly increases at the curing time, around 8 to 10 hours. However, it is noted that concrete strength is not significantly increased when rising temperature.

Based on the above discussion, the trend of research using geopolymer material can replace the traditional material. GPC can reduce the environmental problem when using industrial waste like fly ash, but no national standard discusses this material at present. Therefore, this research focuses on the strength of reinforcement concrete geopolymer beam, is proposed to support more data for discovering the actual properties of this such material. In addition, this study result makes a premise for actual application in the future, specifically for casting concrete technology.

## 2. Materials

Aggregate design of geopolymer concrete using fly ash, alkaline, sodium silicate, and sodium hydroxide to replace 100% cement. The following sections discuss aggregate material.

### *2.1 Fly ash*

In this research, fly ash source is supported by thermal power plants in Nhon Trach industrial zone, Dong Nai province. Table 1 shows the X-ray result of chemical composition. The table shows that $SiO_2$, $Al_2O_3$, and CaO are more than 70% of the total volume, which is the key to replacing partial cement.

**Table 1.** Chemical composition of fly ash.

| Chemical composition | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $Na_2O$ | MgO | $SO_3$ | MKN |
|---|---|---|---|---|---|---|---|---|
| Quanlity (%) | 51.7 | 31.9 | 3.48 | 1.21 | 1.02 | 0.81 | 0.25 | 9.63 |

### *2.2 Alkaline solution*

The alkaline liquid was synthesized using sodium silicate ($Na_2SiO_3$) and sodium hydroxide solution (NaOH). The ratio mixture of sodium silicate to sodium hydroxide is 2.5.

### *2.3 Coarse and fine aggregate*

To produce geopolymer concrete, coarse and fine aggregate is used about 75% of the total volume. The coarse aggregate is with $D_{max}$ of 25mm, and the fine aggregate has a modulus larger than 2.4.

In the research on the impact factor to compressive strength in 2018 [7], the mechanical properties of GPC using fly ash are affected by curing temperature and time, the AS/FA ratio, and the mixture of alkaline solution. This study chose the most effective aggregate to produce GPC, then investigating the effects of the bending strength, Poisson's ratio, and Elastic modulus of beam samples.

### *2.4 Aggregate mixture*

The qualification of aggregate design depends on the target of concrete strength. As shown in Table 2, two OPC concrete samples using PCB cement were designed to achieve compressive strenght of 22.5Mpa and 40Mpa compressive strength, name M250, M400. For the geopolymer concrete samples, coarse and fine aggregate do not change, but cement is replaced 100% by fly ash, Sodium Silicate, Sodium Hydroxide, and Alkaline solution. In more detail, the sample of GPC1, GPC2, and GPC3 use the AS/FA ratios of 0.6, 0.5, and 0.4, respectively.

When doing the experimental research, it is necessary to obtain the requirement of technique and qualify. Hence, all the geopolymer concrete samples are curing at 60°C, 90°C, and 120°C for 4 hours, 6 hours, and 10 hours. The mechanical properties are tested at seven days of age.

### *2.5 Beam*

To investigate the potential application of geopolymer concrete in the structural element. Nine beam samples are constructed for bending test and then comparing to two Ordinary Poland Concrete beams. For each beam sample, the shape dimension is 100mm x 100mm x 400 mm. Confinement steel is □6 at spacing 150mm, and longitudinal reinforcement is four □10 bars. Table 3 shows details of beam samples.

All the beam samples were constructed and tested in the construction laboratory of the Ho Chi Minh University of Technology. Figure 3 presents the test setup, including LVDT and applied load. The test program applied two concentrated vertical loading to the specimens through the load transfer beam. The rate of loading is 50N/s. Displacement at the center of the beam is recorded by LVDT, as shown.

**Table 2.** Concrete mixture (kg/m$^3$).

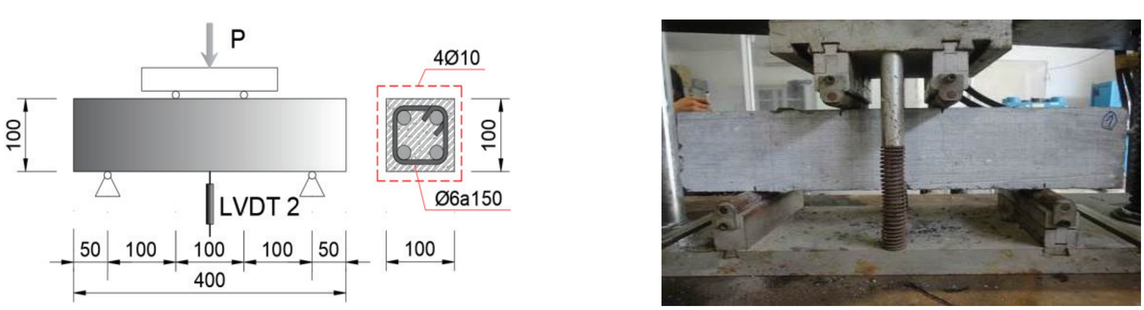
| No. | Rock | Sand | Water | Cement | Fly ash | Sodium Silicate | Sodium Hydroxide (18M) | Alkaline/ Fly ash | Sodium silicate/ Sodium hydroxide |
|---|---|---|---|---|---|---|---|---|---|
| **M250** | 1100 | 650 | 185 | 410 | - | - | - | - | - |
| **M400** | 1100 | 650 | 185 | 490 | - | - | - | - | - |
| **GPC1** | 1079 | 593 | - | - | 418 | 179 | 72 | 0.6 | 2.5 |
| **GPC2** | 1113 | 612 | - | - | 431 | 154 | 62 | 0.5 | 2.5 |
| **GPC3** | 1149 | 632 | - | - | 445 | 127 | 51 | 0.4 | 2.5 |

(a) Concrete sample (100x200) (b) Reinforcement concrete beam sample (100x100x400)

**Figure 2.** Conrete samples before testing

**Table 3.** Details of beam samples.

| No. | Concrete strength | | Dimension | | | Reinforcement steel | |
|---|---|---|---|---|---|---|---|
| | Comp. (MPa) | Bend. (MPa) | Long (mm) | Width (mm) | Height (mm) | Confinement steel | Long bar |
| M250 | 26.7 | 3.1 | 400 | 100 | 100 | F6a150 | 4F10 |
| M400 | 45.5 | 4.04 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC1-60 | 50.8 | 6.35 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC1-90 | 54.4 | 7.27 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC1-120 | 57.2 | 7.73 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC2-60 | 49.7 | 6.29 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC2-90 | 53.6 | 5.87 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC2-120 | 55.0 | 7.76 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC3-60 | 46.3 | 6.11 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC3-90 | 50.7 | 7.05 | 400 | 100 | 100 | F6a150 | 4F10 |
| GPC3-120 | 52.4 | 7.44 | 400 | 100 | 100 | F6a150 | 4F10 |




(a) Test design (b) Test setup

**Figure 3.** Bending test of GPC1 beam sample at seven days of age.

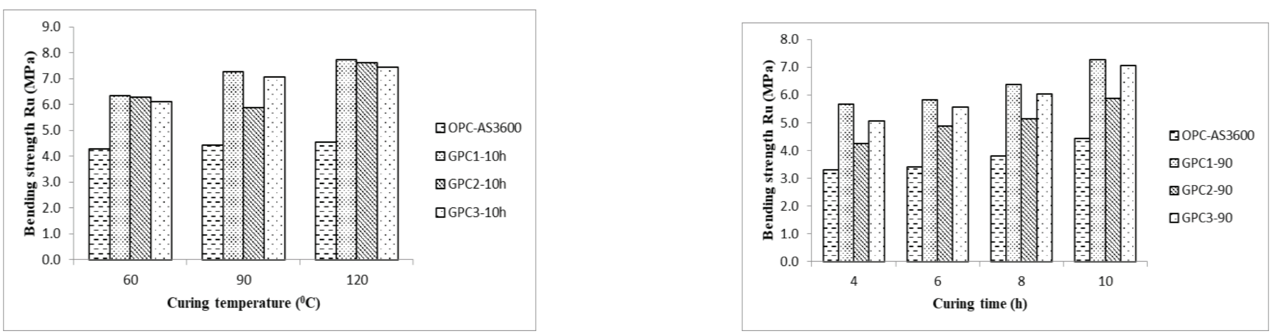
## 3. Result and discussion

### *3.1 Bending strength of geopolymer concrete*

Figure 4 shows the final state of the concrete bending test. At the end of the test, the average bending strength of geopolymer concrete ranks from 4.25Mpa to 7.7 Mpa. Meanwhile, the bending strength of the OPC sample is 3.1Mpa and 4.04Mpa for M250, M400 samples, respectively. As the results are shown in Figure 5 and Table 3, it can be seen that bending strength is affected by the AS/AF ratio and curing conditions. The higher temperature is, the higher the bending strength is. This trend is also suitable for long time curing.

The results indicate that when the ratio of alkaline to fly ash is reduced, the bending strength decrease. Hence, the geopolymerization progress is better by increasing fly ash, that means increasing the amount of Si-Al in alkaline environment. On the other hand, the curing temperature and the curing time based on geopolymer concrete play important roles during re-gopolymerization and affect the bending strength.

**Figure 4.** Bending test of concrete samples.




(a) Behavior between bending strength and curing temperature

(b) Behavior between bending strength and curing time

**Figure 5.** Bending strength of concrete.

### *3.2 Possion's ratio và Elastic modules*

In this study, the Elastic modulus and Poisson's ratio is determined following ASTM C469. The specimens are curing for 24 hours, then curing at $60^0$C, $90^0$C, and 100oC for 10 hours. The Poisson's ratio and Elastic modulus is recorded when the stress reaches 40% of compressive strength. The results present in Table 4.

The Poisson's ratio and young modulus expose the elastic properties of concrete. Table 3 presents the average Poisson's ratio of geopolymer concrete is from 0.16 to 0.21. Normally, this ratio is 0.25 for high-performance concrete and 0.22 for low-strength concrete [10].

Young modulus is a characteristic property of concrete. When support increasing lateral load, modulus is reduced when the cracks occur [13]. In Table 4, the Young modulus of GPC is from 22.5Gpa to 28.0Gpa, and smaller than the standard OPC concrete, from 34.16 to 38.33 Gpa [11]. This demonstrates that the young modulus of GPC is not affected by aggregate, but it depends on a uniform geopolymer structure [12]. In the curing condition, A/F and SS/SH ratio also react to the uniform property of geopolymer structure.

**Table 4.** Poisson's ratio and Elastic modulus.

| No. | Compressive strength $R_n$ (MPa) | Elastic modulus $E_c$ (GPa) | Poisson's ratio $\upsilon$ |
|---|---|---|---|
| GPC1 | 50.8 | 25.10 | 0.18 |
| | 54.4 | 25.40 | 0.19 |
| | 57.2 | 24.20 | 0.19 |
| GPC2 | 52 | 21.90 | 0.18 |
| | 53.6 | 25.50 | 0.16 |
| | 55.0 | 24.90 | 0.18 |
| GPC3 | 46.3 | 22.80 | 0.19 |
| | 49.7 | 22.60 | 0.21 |
| | 52.4 | 28.00 | 0.19 |

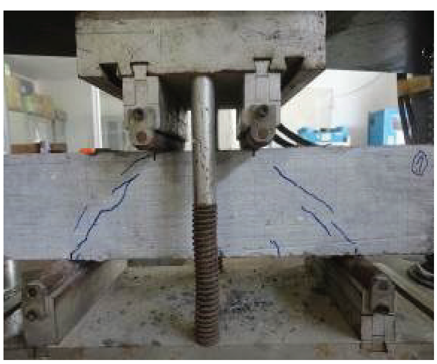
### *3.3 Bending behavior of beam*

The bending test results are presented in Table 5. At the early lateral load, the flexural cracks occur tension area of the center-section with the maximum internal moment. These first crack is recorded and shows the cracking strength of specimens. The result shows that the cracking strength of GPC beam is more significant than OPC beam. At the peak applied load, as shown in Figures 6 and 7, the ultimate flexural strength of the GPC beam is hugely higher than the OPC beam. It is from 50.8 kN to 57.2 kN for the GPC beam and 26.7 kN and 45.5 kN for M250 and M400, respectively. The shear crack causes failure mode for both GPC beam and OPC beam specimens because of the insufficient confinement steel.

Besides, the ultimate strength of GPC beam is more significant than 25% of OPC beam. The displacement at the center GPC beam is more extensive than OPC beam at peak load condition. The vertical displacement at the center beam is from 5.08mm to 7.29mm for GPC beam, and it happens from 1.58mm to 2.06 mm for OPC beam. It is demonstrated that the ductility of GPC beam is better than OPC beam. Because of using the same reinforcement method, it is effortless to explain for this enormous strength of GPC beam that the structural properties of GPC are affected by the continuous chain of Si-O-Al.

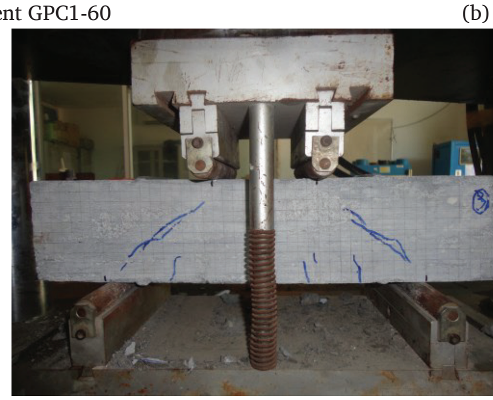
**Table 5.** Results of beam bending test.

| No. | Compressive strength $R_n$ (MPa) | Cracking Strength $R_{cr}$(kN) | Ultimate strength $R_{fu}$ (kN) | Vertical displacement (mm) | Collapsed time (min.) |
|---|---|---|---|---|---|
| M250 | 26.7 | 12.61 | 37.02 | 1.58 | 20 |
| M400 | 45.5 | 17.23 | 53.08 | 2.06 | 30 |
| GPC1-60 | 50.8 | 18.64 | 96.07 | 5.46 | 32 |
| GPC1-90 | 54.4 | 27.40 | 132.08 | 6.61 | 44 |
| GPC1-120 | 57.2 | 16.24 | 110.49 | 5.59 | 37 |
| GPC2-60 | 49.7 | 20.75 | 100.07 | 5.38 | 30 |
| GPC2-90 | 53.6 | 18.24 | 115.34 | 5.57 | 38 |
| GPC2-120 | 55.0 | 12.81 | 124.07 | 5.21 | 41 |
| GPC3-60 | 46.3 | 12.54 | 55.18 | 7.29 | 20 |
| GPC3-90 | 50.7 | 9.16 | 65.26 | 5.22 | 21 |
| GPC3-120 | 52.4 | 15.79 | 76.07 | 5.08 | 25 |



(a) Speciment GPC1-60

(b) Speciment GPC1-90



(c) Speciment GPC1-120

**Figure 6.** Bending test of specimen GPC1-60, GPC1-90 and GPC1-120 at peak load.

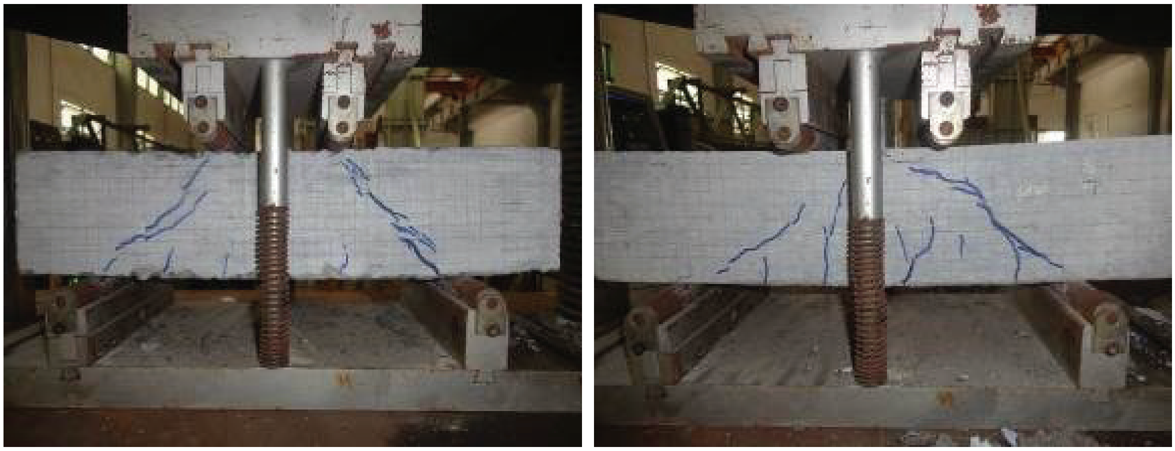


**Figure 7.** Bending test of specimen M250, M400 at peak load.

## 4. Conclusion

By the experiment on the behavior of GPC, which is comparing to OPC concrete. The following conclusions can be drawn:

- ✓ The higher strength of GPC is achieved in this study. Because the geopolymerization progress creates the polymer chain that continuously connects to create micro-structure. The modulus of coarse arrogate and micro-structure is the main factor of higher strength.
- ✓ The bending strength of GPC is higher than 30% of OPC. In addition, the elastic modulus of GPC is from 22.5 Mpa to 28.0 Mpa that is smaller than OPC. Meanwhile, their Poisson's ratios are the same approximately. Because GPC has a polymer structure with the connection of Si-O-Al chains, this causes the increase of tension and bending strength.
- ✓ The advantage of the machinal properties of GPC is proof by the beam bending test. Flexural cracking and ultimate strength of GPC are also higher than OPC beam. The ultimate strength of GPC is from 50.8 kN to 57.2 kN and from 26.7 kN to 45.5 kN for OPC beam. The failure mode of both types of concrete beams is shear failure because the confinement capacity is insufficient. This test indicates that GPC can use to replace the OPC for strengthen and environmental problems.
- ✓ The economic benefit is ignored in this study. However, this study presents an efficient issue for those who want to be considered GPC in economic solutions.

## References


[1]. Djwantoro Hardjito, Chua Chung Cheak & Carrie Ho Lee Ing, *Strength and Setting Times of Low Calcium Fly Ash-based Geopolymer Mortar*, Department of Civil & Construction Engineering Curtin University of Technology, Sarawak Campus.

[2]. Djwantoro hardjitoc and Shaw Shen Fung, *Parametric Study on the Properties of Geopolymer Mortar Incorporating Bottom Ash,* Civil and Construction Engineering, School of Engineering and ScienceCurtin University of Technology, Sarawak, Malaysia, APSEC 2009.

[3]. J.Davidovits, Davidovits, R., and James, *The Proceeding of Geopolmer 99.* 2nd International Conference on Geopolymers, 1999: p. 368.

[4]. P.Duxson, A.Fernandez-Jimenez, J.L.Provis et al, *Geopolymertechnology : the current state of the art*, Advances In Geopolymer Science & Technology, 42:2917-2933, 2006.

[5]. Palomo, A., Grutzeck, M.W., & Blanco, M.T., *Alkali-activated fly ash cement for furthure.* Cement and Concrete Research, 1999.

[6]. Van Jaarsveld, J.G.S., Van Deventer J.S.J., & Lukey, G.C., *The effect off composition and temperature on the properties of fly ash and kaolinite-based geopolymers.* Chemical Engineering, 2002.

[7]. Lê Hữu Quốc Phong, Nguyễn Thanh Tú, *Nghiên cứu ảnh hưởng của quá trình geopolymer đến cường độ chịu nén của bê tông geopolymer sử dụng tro bay*, Hội Thảo "Kiến trúc và Xây dựng hướng đến phát triển bền vững năm 2018", Trường ĐH Thủ Dầu Một (Bình Dương).

[8]. Australian Standard 3600, Concrete Structure, 2001. Standards Australia International.

[9]. ASTM C469, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of concrete in Compression, 1994.

[10]. AM. Neville, *Properties of concrete* 2000. Sir Isaac Pitman & Sons Ltd., London

[11]. Olivia, Monita, *Durability Related Properties of Low Calcium Fly ash based Geopolymer Concrete*, in *Civil Engineering*2011, Curtin University of Technology.

[12]. P, Duxson, et al., *Understanding the relationship between geopolymer composition, microstructure and mechanical properties.* Collois and Surfaces A : Physicochemical and Engineering Aspects, 2005: p. 47-58.

[13]. A.R.Santhakumar, *Concrete Technology*, Oxford University Press, 2006.

[14]. Nuruddin, Muhd Fadhil, et al., *Compressive strength and interfacial transition zone characteristic of Geopolymer concrete with different cast In-Situ curing conditions.* International Scholarly and Scientific Research&Innovation, 2011.